BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is related to optical devices; more particularly, the invention relates to non-mechanical optical wavelength selective switches.

2. Description of Related Art

Fiberoptic wavelength division multiplexing (WDM) has emerged as the dominant platform for telecommunications, providing a major leap in capacity by enabling a single fiber optic cable to transmit multiple waves of light at once thereby multiply increasing communication bandwidth. WDM systems transmit information by employing optical signals of a number of different wavelengths, known as carrier signals or channels. Each carrier signal is modulated by one or more information signals. For further bandwidth expansion, intelligent optical networks in which optical channels can be dynamically routed/switched in the optical layer become critical. Therefore, wavelength selective optical routers/switches are a key component in the next-generation optical networks, analogous to the electrical switches in electrical networks. Optical wavelength selective switches can be used to perform basic WDM functionalities, such as optical signal routing, channel add/drop, and dynamic multiplexing/demultiplexing. However, optical wavelength selective switching has not been widely adopted because the lack of commercially available components of needed reliability.

In an optical switch, light signal must be accurately entered into an optical fiber, or much of the signal strength will be lost. The alignment requirements of micro-optic devices are particularly stringent, as fiber core diameters are typically as small as 2 to 10 micrometers and their acceptance angle is fairly narrow. Additional insertion losses reduce the amplitude of the optical signal. Therefore, optical switches which accept light from an input optical fiber, and which selectively couple that light to any of a plurality of output optical fibers must transfer that light with precise alignment and within the small acceptance angle for light to efficiently enter the fiber. Current optical wavelength selective switching are achieved by coupling optical filters with mechanical optical switches, consequently have drawbacks of slow, less reliable, and bulky. One such mechanical wavelength selective switch is described in Lee U.S.

Pat. No.6192174. It is therefore greatly desirable to have integrated optical wavelength selective switches that direct light beams according to their wavelength without moving parts, a feature generally associated with high reliability and high speed.

A none-mechanical optical wavelength selective switch has been proposed by Wu et al. FIG. 1 depicts a typical optical wavelength switch 999 of the prior art as described in U.S. Pat. No. 5,694,233, issued to Wu et al. on Dec. 2, 1997, which is incorporated herein by reference. A WDM signal 500 containing two different channels 501, 502 enters interleaver 999 at an input port 11. A first birefringent element 30 spatially separates WDM signal 500 into horizontal and vertically polarized components 101 and 102 by a horizontal walk-off. Components 101 and 102 are coupled to a two-aperture polarization rotator 40 accordingly. The rotator 40 selectively rotates the polarization state of either signal 101 or 102 by a predefined amount to render their polarization parallel. The polarization rotator 40 consists of two sub-element rotators that form a complementary state, i.e. when one aperture turns on the other turns off. By way of example, in FIG. 1 signal 102 is rotated by 90 ° so that signals 103, 104 exiting rotator 40 are both horizontally polarized when they enter a wavelength filter 61.

Waveplate-based wavelength filter 61 selectively rotates the polarization of wavelengths in either the first or second channel to produce filtered signals 105 and 106. For example wavelength filter 61 rotates wavelengths in the first channel 501 by 90° but does not rotate wavelengths in the second channel 502 at all. The filtered signals 105 and 106 then enter a second birefringent element 50 that vertically walks off the first channel into beams 107, 108. The second channel forms beams 109, 110. A second wavelength filter 62 then selectively rotates the polarizations of signals 107, 108 but not signals 109, 110 thereby producing signals 111, 112, 113, 114, having polarizations that are parallel each other. A second polarization rotator 41 then rotates the polarizations of signals 111 and 113, but not 112 and 114. The resulting signals 115, 116, 117, and 118 then enter a third birefringent element 70. Third birefringent element 70 combines signals 115 and 116, into the first channel, which is coupled to output port 14. Birefringent element 70 also combines signals 117 and 118 into the second channel, which is coupled into output port 13.

As described above, by suitably controlling the polarization rotation induced by rotators 40 and 41, device 999 operates as a wavelength selective switch. Furthermore, the wavelength

selective switch 999 can also operates as a passive interleaver multiplexer or de-multiplexer using a fixed sets of polarization rotators in 40 and 41.

Wavelength selective 999 has major drawbacks. First, Wu's switch is disadvantageously based on a large spatial separation between two fibers located on the same side. The configuration requires individual imaging lens for each fiber port and consequently needs large and long crystals to deflect the beams. The use of three separated collimators to couple the signals into and out of optical fibers adds size, complexity, and cost. Moreover, the long coupling distance increases loss. The bulky size also leads to in-stability, since the greater the mass of birefringent materials, the more unstable its operation. As a result, the optical wavelength switch 999 typically has large loss, excessively large size, and is expensive to produce and less stable in operation. Second, the electrically controllable polarization rotators 40 and 41 are based on a two-part-aperture design that rotates the optical beams separately in a complementary manner, i.e. when one turns on the other turns off. Such design is primarily for incorporation of organic liquid crystal device (LCD) based polarization rotators. Since LCD usually employs surface electrodes in the light path to apply electrical field, consequently two individually controllable rotators can be easily fabricated on a same element via electrode patterns. However, the use of liquid crystal materials leads to undesirable properties of slow speed and large temperature dependence, which are obstacles for optical network applications. Recent progresses in inorganic magneto-optic and electro-optic materials have opened new opportunities to produce solid-state optical switches of faster speed and high stability. However, the two-part separately controlled polarization rotator 40 and 41 design in 999 is unsuitable for incorporating inorganic crystals. This is because it is very difficult and unpractical to apply two opposite fields with reasonable uniformity to two adjacent Faraday crystals or electro-optic crystals, due to the strong field interference across the small spatial separation.

Recent version of optical interleaver as described by Li, U.S.Pat.No.6212313 represents some improvement by using dual fiber sharing a single imaging lens to reduce the optical device size. However, Li's wavelength selective devices are primarily designed for passive interleaver applications. It thus has a disadvantage to be reconfigured as a active wavelength

selective switch, since that it is based on the same two-part-aperture polarization rotator design as described in Wu's design. For reasons described above, Li's designs are unsuitable for wavelength switching/routing applications using solid-state materials of magneto-optic garnet or electro-optic crystals as the controllable polarization rotators. Moreover, Li's reflection type optical configurations are based on use of either three separated collimators or a triple collimator on one side to couple the signals into and out of optical fibers. Using three individual collimators significantly adds size and cost. Using a triple collimator substantial increase complexity, resulting in increased interdependency among the alignments of each optical path. Therefore, manufacture of Li's devices is difficult and the production cost is high.

Due to the above difficulties, solid-state wavelength switch has not yet been commercially available. There is a need, therefore, for an improved optical wavelength switch that overcomes the above drawbacks. It would be particularly desirable to provide optical wavelength selective switches having low optical insertion loss and high speed switching speed that is also reliable. Its is also important that these switches use components of small size and require reduced alignment steps with large assembly tolerance to facilitate low cost manufacture. The inventive optical devices described here provide these critical attributes.

SUMMARY OF THE INVENTION

The present invention provides a compact and economical non-mechanical optical wavelength selective switch that can be efficiently coupled to optical fibers using fewer parts and having large assembly tolerance. The inventive three fiber ports devices divide the incoming WDM optical signals into two subsets of channels and switchably direct them into two output ports in response to an electrical control signal. The invention allows the use of inorganic crystals to achieve fast and stable wavelength switching and filtering functions. The inventive wavelength selective switches use at least one single lens to coupling two fibers achieving small beam separation thus small size and low material cost. The invention further consists of a light-bending device, situated to compensate for the angle between the two light beams that share the same lens, advantageously increasing alignment tolerance.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts an isometric view of an optical wavelength switch according to the prior art;

FIG. 2 is an isometric view of a three-ports two-stage optical wavelength selective ***switch*** according to a first embodiment of the present invention.

FIG. 3 is a plan view of a nonreciprocal optical ***wavelength switch*** of FIG.2, and illustrates the arrangement of each element within the ***switch*** body for this embodiment. FIGS.3A and 3B are top view and side view of the inventive switch, respectively.

FIG.4 depicts cross section schematic views of polarization of FIG. 3 after each component as the optical signal travels along the optical paths, in accordance with the invention.

FIG.5 depicts an isometric view of a reflection mode nonreciprocal two-stage optical ***wavelength switch*** according to a second embodiment of the present invention.

FIG.6 depicts an isometric view of a reflection mode bi-directional two-stage optical ***wavelength switch*** according to a third embodiment of the present invention.

FIG.7 depicts an isometric view of a reflection mode passive optical wavelength ***interleaver*** according to a fourth embodiment of the present invention.

FIG.8 depicts an isometric view of a reflection mode bi-directional two stage optical light path ***switch*** according to a fifth embodiment of the present invention.

DETAILED DESCRIPTION OF THE SPECIFIC EMBODIMENTS

The solid-state optical wavelength selective switch of this invention has several advantages over prior designs. First, the inventive configuration places two fiber ports on the same side to be closely next to each other and to share the same imaging element, leading to fewer optical elements. The closely spaced beam propagation arrangement reduces the size requirement for each birefringent beam deflection element, consequently lowering material cost. The design also results in a smaller footprint of the devices. Prior non-mechanical optical wavelength switches have an arrangement wherein each optical port has its own individual imaging element, disadvantageously requiring larger and longer size of each component that comprises the device. Second, the design incorporates a beam angle correction system, allowing to adjust position and angular substantially independent, reducing position sensitivity and achieving maximum light coupling. This inventive configuration greatly reduces the packaging difficulty, therefore, is particularly desirable for volume production. Third, the inventive switches are based on electrically controllable polarization rotators of single aperture. This simple configuration is better suited for using magneto-optic Faraday crystals or inorganic electro-optic materials as the controllable polarization rotator. Prior non-mechanical optical wavelength switches have disadvantageous configurations wherein the controllable polarization rotators comprise two-parts aperture of different rotations that is not amiable for using inorganic materials.

In one aspect of the invention, an optical signal of different channels may be rapidly and reliably switched between two optical paths, according to electrical control signals. The inventive optical wavelength switch may be used in telecommunications systems/sub-systems, such as in WDM add/drop, multiplexers/demultiplexers, dynamic reconfiguration, signal routing. The inventive optical wavelength selective switches are particularly suited for WDM optical network applications, where high speed and reliable switching is required. These and other advantages of the inventive optical switches are elaborated in the specific embodiments now described.

The wavelength switch described here is a polarization-rotation based device in which a randomly polarized input light beam is split into a pair of beams of two polarizations; its optical wavelength is further split into two sets of complementary spectrums of different polarizations by passing through waveplate-based filters; the light beams with on spectrum

goes to one fiber but that with another spectrum goes into another fiber. The electrically controlled polarization rotators switch the state of polarization of the light beams from one to another, consequently switch the two sets of wavelength from one port to another port. The inventive device advantageously achieves routing while conserving all optical energy regardless of the polarization of signals.

The inventive devices achieve wavelength selection by passing light through at least one birefringent crystal filter. The principle of its wavelength filtering function can be described as the following. For a uniaxial crystal cut parallel to the optic axis, it introduces a relative phase difference $\Delta\delta$ between the two polarization components of the incident light wave. This phase shift can be expressed as:

$$\Delta\delta(\lambda)=2\pi\,|n_o(\lambda)-n_e(\lambda)|\,L/\lambda \quad\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where L is the crystal length, and n_o (λ) and n_e (λ) are its ordinary and extraordinary refractive indices, respectively.

When $\Delta\delta$ equals to $2k\pi$ (k=0,1,2, ...), the relative retardation is one wavelength, the two polarization components are back in-phase, and there is no observable effect on the polarization of the incident monochromatic beam. However, when $\Delta\delta$ is equal to $(2k+1)\pi$ (k=0,1,2,...), the effect of the crystal in the light path is to rotate the polarized plane of the incident light by an angle between the incident vibrations and the principle section. When the crystal's principle axis is oriented at an angle of 45° with the incident polarization plane, the vibration of the emerging light will rotate 90° with its original direction.

Since the phase shift is also a function of wavelength, with a particular crystal length L, the birefringent crystal can introduce a $2k\pi$ (k=0,1,2,...) phase difference to λ_1 as well as a $(2k+1)\pi$ (k=0,1,2,) phase difference to λ_2 simultaneously. These L values can be determined by following equations:

$$\left\{ \Delta\delta(\lambda_1)=2\pi\,|n_o(\lambda_1)-n_e(\lambda_1)|\,L/\lambda_1=2k\pi \quad k=0,1,2,\ldots \right.$$

$$\left\{ \begin{array}{l} \\ \Delta\delta(\lambda_2)=2\pi\,|\,n_o(\lambda_2)-n_e(\lambda_2)\,|\,L/\lambda_2=(2k+1)\pi \quad k=0,1,2,\ldots \end{array} \right. \qquad \ldots\ldots\ldots\ldots (2)$$

Therefore, with a proper thickness and optic axis orientation, a birefringent crystal can selectively rotate the polarization of λ_2 by 90° and at the same time maintains the polarization of λ_1, as a light beam containing λ_1 and λ_2 transmits through the birefringent crystal filter. The effect of the birefringent waveplate filter for the incident light's entire wavelength spectrum is generating two eigen states. The first eigen state carries a first sub-spectrum with the same polarization as the input, and the second eigen state carries a complementary sub-spectrum at the orthogonal polarization. For WDM siganls, these eigen state wavelengths are the ITU values and the two sets of the eigen states interleaver each other. The crystals used in the filter can be designed with different lengths and with different materials. These crystals can be placed in series to achieve various wavelength interleaving spectrum, such as flat top, and also to compensate temperature as well as dispersion effects.

The present invention will be further described in terms of several optical wavelength switch embodiments having specific components and having specific configurations.

Two Stage Wavelength Selective Switch

Fig.2 schematically depicts an embodiment of a 3 ports two-stage inventive non-mechanical optical wavelength switch. The invention relates to an optical switch comprising several optical components which are optically coupled along the longitudinal axis: a pair of beam displacer/combiner **12** and **13** that displaces at least one optical beam into two polarized component beams and combines at least two polarized component beams to form an optical beam; a pair of two-aperture halfwave plate **14** and **15**, for rotating the polarization of the beams such that both beams have the same polarization state or rotating two parallel polarization beams into orthogonal polarizations; a pair of electrically controllable rotator **16** and **17** for rotating the polarization orientation of the polarized component beams upon an electrical signal to direct beams between two paths; a pair of birefringent filters **18** and **21** that selectively rotate the polarization of wavelengths to produce filtered signals; a polarization walk-off crystal **20** which shifts one set of the polarization beam laterally to form a second

path; and a beam angle deflector **19** that deflects all beams with a correction angle such that both optical paths are coupled into the dual collimators that have an angular between the two beam propagations. The switch has two stage cascaded configuration.

To more particularly illustrate the method and system in accordance with the present invention, refer now to FIGS. 3 and 4 depicting one embodiment of a three ports two-stage (1×2) optical wavelength switch. FIG. 3A depicts a top cross-section view of optical switch and FIG. 3B depicts a side cross-section view of the optical switch. FIG.4 further depicts the propagating beams' polarization states as they exit each component. A first optical fiber **1** is inserted into a first collimator **10**. Opposite first fiber **1**, a second optical fiber **2** is inserted into a second collimator **11** and a third optical fiber **3** is inserted into the same collimator **11** adjacent to fiber **2**, so that fiber **2** and fiber **3** are parallel. Beam propagations from fiber **2** and fiber **3** has an angle with respect to the y-axis caused by the focus lens inside the collimator.

As shown in Fig.4, beam **30** that contains the full spectrum of data passes through a first birefringent block **12** and is thereby divided into two beams having orthogonal polarizations, specifically beams **30A** and **30B**. The length of birefringent block **12** is adjusted to obtain a spatial separation between beams **30A** and **30B**, which permits to pass them through independent optical elements, such as two-aperture waveplate **14**. Beam **30A** then enter a first halfwave plate **14** which rotates its plane of polarization by 45° clockwise. Beam **30B** enter another part of the first halfwave plate **14** which rotates the plane of polarization by 45° counterclockwise. Therefore, halfwave plate **14** renders the polarizations of beam **30A** and **30B** parallel to each other.

Considering a first switching state in which light path of the spectral band that contains λ_1 is from port **1** to port **2** and the complementary spectral band that contains λ_2 is guided out through port **3**, as indicated in Fig.4A. In this light path sate, both beams enter the first electrically controllable polarization rotator **16** which rotates the plane of polarization by 45° clockwise with a corresponding electrical control current. The beams then pass through a birefringent filter **18** which rotates the polarization of λ_2 spectrum band by 90° but passes the spectrum band containing λ_1 unaltered. Beam **30** is now further decomposed into two sets of orthogonally polarized beams: beams **31A** and **31B** for the λ_1 spectrum band and beams **32A** and **32B** for the λ_2 spectrum band, as shown in Fig.4A. The two spectrum bands are

subsequently spatially separated by a birefringent walk-off element **20** which changes the propagation of **32A** and **32B** of λ_2 spectrum band with a spatial displacement in x-axis.

All the beams than pass through the second stage birefringent filter **21** which rotates the polarization of beams **32A** and **32B** by 90° but passes beams **31A** and **31B** unaltered.

At this point both beams propagate parallel to the longitudinal y-axis which need to be bent at an angle θ with respect to the y-axis in order to be efficiently coupled into the dual fiber collimator **11**. A polarization-independent light-bending device **19** corrects this angle of propagation.

All beams than pass through the second electrically controllable polarization rotator **17**, which rotates their polarization by 45° counterclockwise by applying an associated electrical current flow. All four beams further enter a halfwave plate **15**, which selectively rotates the polarization of **32B** and **31B** by 45° counterclockwise and rotates **32A** and **32A** by 45° clockwise. Block **13** subsequently combines orthogonally polarized beams **31A** and **31B** to form a single beam **31** that is also focused on optical fiber **3.** Similarly, block **13** combines beams **32A** and **32B** to form a single beam **32** that is focused on optical fiber **2.** Therefore an optical path from fiber port **1** to fiber **2** for the λ_1 wavelength band and another optical path from fiber port **1** to fiber **2** for the λ_2 wavelength band are established, when an appropriate control signal is applied to both electrically controllable Faraday rotators **16** and **17**.

Next, considering a second wavelength switching state in which light path for λ_1 spectral band is from port **1** to port **3** and for the complementary λ_2 spectral band is from port **1** to port **2**, as indicated in Fig.4B. In this light path sate, both beams **30A** and **30B** enter the first controllable Faraday rotator **16** which rotates the plane of polarization by 45° counterclockwise with a corresponding current, rendering them in the horizontal direction, as seen in Fig.4B. Birefringent filter **18** rotates the polarization of λ_2 spectrum band by 90° but does not change λ_1 spectrum band. The two spectrum bands are subsequently spatially separated by a birefringent walk-off element **20** which alters the propagation of λ_1 spectrum band with a spatial displacement. Beam **30** is thereby further divided into four beams: **31A** and **31B** for the λ_1 spectrum band and **32A** and **32B** for the λ_1 spectrum band.

All four beams than pass through the second stage birefringent filter **21** which rotates the polarization of beams **31A** and **31B** by 90° but passes beams **32A** and **32B** unaltered. A

polarization-independent light-guiding device **19** further bends the beams an angle θ with respect to the y-axis to facilitate coupling into the dual fiber collimator **11**.

All beams than pass through the second electrically controllable polarization rotator **17**, which rotates their polarization by 45° clockwise by applying an associated electrical current flow. All four beams further enter a halfwave plate **15**, which selectively rotates the polarization of **32B** and **31B** by 45° counterclockwise and rotates **32A** and **32A** by 45° clockwise. Block **13** subsequently combines orthogonally polarized beams **31A** and **31B** to form a single beam **31** that is also focused on optical fiber **3.** Similarly, block **13** combines beams **32A** and **32B** to form a single beam **32** that is focused on optical fiber **2.** Therefore an optical path from fiber port **1** to fiber **2** for the λ_2 wavelength band and another optical path from fiber port **1** to fiber **3** for the λ_1 wavelength band are established, when a control signal that is opposite to that of the first switching state is applied to both Faraday rotators **16** and **17.**

The above embodiment is a nonreciprocal device using electrically controllable polarization rotators **16** and **17** of 45° magneto-optic Faraday rotators. Another preferable embodiment of Fig.2 is a reciprocal wavelength switch. The reciprocal embodiment requires strait forward modifying the halfwave plate **14** and **15** and using controllable polarization rotators **16** and **17** of 90° rotation in the above nonreciprocal embodiment. Both magneto-optic Faraday rotators and electro-optic retarders can be used to construct the 90° rotator **16** and **17** in the reciprocal wavelength switch embodiment. As described in our pending U.S. patent application, an inventive reciprocal Faraday rotator that comprises a switchable first 45° garnet and a second permanent 45° polarization rotation garnet is applicable to be used as electrically controllable polarization rotators **16** and **17** in a bi-directional wavelength switch embodiment. The combined Faraday rotator rotates light polarization between 0° when the two garnet rotations cancel each other and 90° when the two garnet rotations are in the same direction. An electro-optic rotator configuration with side electrodes described in our pending patent is also applicable here to be used as electrically controllable polarization rotators **16** and **17** in the reciprocal wavelength switch embodiment.

In one embodiment, the Faraday polarization rotator comprises yttrium-iron-garnet (YIG), or Bi-added thick film crystals with a low field of saturation, such as less than 200(Oe) to reduce power consumption. One example of such materials is bismuth-substituted rare earth

iron garnet single crystal system represented by a chemical formula $(GdRBi)_3(FeGaAl)_5O_{12}$, where R denotes at least one element selected from the group consisting of yttrium (Y), ytterbium (Yb) and lutetium (Lu). The electro-magnet coupled to Faraday rotator comprises primarily cupper coils. Ion alloys are often incorporated into the electro-magnet to improve electrically induced magnetic field strength. Semi-hard magnetic metallic alloys can be used to achieve latching performance, although this is not essential for self-latching type garnets. Therefore, the inventive switch requires only current pulse to switch optical path from one to another by reversing the polarity and latches to the previous switching state even when the current is removed.

The general requirement for the electro-optic phase retarder used in the inventive switches is that, when a voltage is applied, a polarization rotation of 90° or ± 45° is produced. Preferably, the material has a high electro-optic coefficient to reduce operating voltages to less than 500 volts, good thermal stability, and good transparency at the wavelength of interest, e.g., between 1200 nm and 1600 nm. These requirements are satisfied by a class of ferroelectric complex oxides which have a Curie temperature less than about 600° C, so that electro-optic coefficients are high in the operation temperature range. Example material systems are: a solid solution of lead manganese niobate and lead tantalate (PMN-PT) and a solid solution of lead niobate zirconate and lead tantalate (PNZ-PT), lead manganese niobate (PMN), lanthanum modified PZT (PLZT), and More members of this class may be discovered in the future. It is particularly preferable to use single-crystal of the said class of ferroelectric materials, providing good repeatability and temperature independent operation. Another family of electro-optic materials applicable to the inventive switches is new solid organic materials, such as polymers and organic crystals with large electro-optic effect. Solid organic electro-optic materials have an advantage of higher switching speed due to their relatively smaller dielectric constant.

There are many methods to make light-bending device **19**. One embodiment of device **19** consists of a tapered glass prism, whose angle is adjusted so that beams enter from fiber port **2** and **3** are rendered parallel to the y-axis as the beams exit device **19**. Other shapes and constructions of prisms can also perform the same function. In another embodiment, the light guiding device **19** can be constructed using two tapered birefringent plates usually from the

same birefringent material to change angle of propagation. Two such examples are Wollaston type and Rochon type prisms.

The above device is a specific embodiment. However, one of ordinary skill in the art will readily recognize that this method and system will operate effectively for other components having similar properties, other configurations, and other relationships between components.

Reflection Mode Wavelength Selective Switch

An alternative embodiment of the present invention is a folded three ports optical wavelength selective switch configuration, which uses fewer and shorter components than the strait embodiment. FIG. 5 depicts a specific nonreciprocal dual stage reflection mode (1×2) wavelength selective switch configuration. By use of a right angle prism **22**, this reflection mode switch essentially folds the straight switch in Fig.2 from the center. Therefore, the reflection configuration advantageously eliminates the need for elements **21**, **17**, **15**, and **13** as well as shortens the lengths of birefringent elements **18** and **20** by half due to the double passes. A dove type prism type position displacer **23** is incorporated here to provide larger separating between collimator **10** and **11** for ease of manufacturing. A plate **24** is also added to compensate the traveling distance difference between the two polarization components caused by birefringent crystal **12**. In this embodiment the switchable polarization rotator **16** is a 45° Faraday garnet rotator. The operation principle can be easily understood in the same way as the above embodiments by following the ray traces illustrated in FIG.5.

FIG. 6 depicts an example of bi-directional single-stage reflection-mode wavelength switch. In this embodiment the switchable polarization rotator **16** is a 90° rotator of Faraday garnets or an electro-optic crystal, similar to the strait version discussed above. In this configuration, **14** comprises a halfwave 90° rotator bottom aperture and a polarization mode-dispersion compensation plate top aperture. This inventive configuration uses less components than the above embodiments.

Reflection Mode Wavelength Interleaver

The inventive device can also be configured as a passive optical wavelength interleaver. FIG. 7 depicts a passive reflection interleaver embodiment. This inventive device uses fewer components and has increase alignment tolerance than prior arts. Therefore, it is easier to be produced and its cost is lower. The operation principle can be easily understood by following the ray traces illustrated in FIG.7, the same way as described in the above sections.

Reflection Mode Wavelength Independent Switch

The inventive device can be further configured to function as wavelength-independent optical light path switches by simply removing wavelength filter **18**. FIG. 8 depicts a bi-directional 1x2 optical switch embodiment. A light beam **1** is launched through first collimator **10**, displaced spatially by a prism **23**, so that alignments of collimator **10** and **11** are made easier. The input beam is then decomposed into two orthogonally polarized components and spatially separated by walk-off crystal **12.** Their polarizations are consequently rotated by halfwave plate **14** rendering them parallel in the z direction. Considering a first switching state in which light path is from **1** to **2**, as indicated by solid beam propagation line in FIG. 8. In this light path sate, electrically controllable polarization rotator **16** rotates the plane of polarization by 0°. The two beams then pass a birefringent walk-off element **20** unaltered. Right-angle prism **22** polarization-independently reflects back the beam with a displacement in x direction. The reflected beams pass **20** without change but are bended by **19** at an angle that matches the coupling angle of second collimator **11**. Again, the reflected beams pass **16** without rotation. Halfwave plate **14** renders the parallel polarized reflected beams orthogonal and block **12** combines the two beams to form a single beam that is focused to optical fiber **2** mounted in collimator **11**. Therefore an optical path from fiber port **1** to fiber **2** is established, when no rotation is applied to rotator **16**.

Next, considering a second switching state in which light path is from port **1** to port **3**, as shown in FIG. 8 by the dotted beam propagation line. Similarly, fiber **1** emits a light beam that becomes two vertically polarized beams after **14**. In this light path sate, electrically controllable polarization rotator **16** rotates the plane of polarization by 90°. The two horizontally polarized beams are then displaced at a distance in x direction by passing birefringent walk-off element **20**. Right-angle prism **22** reflects back the beam with another

displacement in x direction. The reflected beams pass **20** with another further displacement in x direction and are bended by **19** at an angle. Again, the reflected beams pass **16** with a second stage 90° rotation. Halfwave plate **14** renders the parallel polarized beams orthogonal and block **12** combines the two reflected beams to form a single beam that is focused to optical fiber **3**. Therefore an optical path from fiber port **1** to fiber **3** is established, when a 90° rotation is applied to rotator **16**.

The above descriptions of the 1×2 embodiments are very specific examples. It will be apparent to a person of average skill in the art that many variations of the switch are possible within the scope of the invention. Accordingly, the scope of the invention should be determined by the following claims and their legal equivalents.